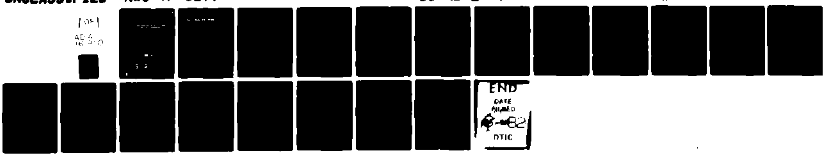
AD-A116 810 NAVAL WEAPONS CENTER CHINA LAKE CA F/G 19/1

DEFINITIVE QUANTITY-DISTANCE TABLES FOR STORES OF EXPLOSIVES.(U)

SEP 81 G F KINNEY, R G SEWELL, K J GRAHAM

UNCLASSIFIED NWC-TP-6277 SBI-AD-E450 027 NL



AD-E450027 (12)

NWC TP 6277

AD A116810

Definitive Quantity-Distance Tables for Stores of Explosives

by
Gilbert F. Kinney
Robert G. S. Sewell
Kenneth J. Graham
Research Department

SEPTEMBER 1981

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA 93555

Approved for public release; distribution unlimited.

Naval Weapons Center
AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

FOREWORD

This investigation was undertaken as part of a continuing effort to strengthen our capabilities in support of blast studies. Specifications for safety distances from stores of explosives date back to 1910, and have been modified from time to time since then. Our current tables now need adjustment, and for two reasons. One is recent theoretical studies show that impulse is an important aspect of blast damage criteria. The other reason is our forthcoming necessity to convert to metric units.

The work was performed during Fiscal Years 1980 and 1981. It was funded by Director of Navy Laboratories Programs Task Assignment ZR000-01-01.

This report was reviewed for technical accuracy by James A. Weeks.

Approved by
E. B. ROYCE, *Head*
Research Department
4 September 1981

Under authority of
J. J. LAHR
Capt., U.S. Navy
Commander

Released for publication by
R. M. HILLYER
Technical Director

NWC Technical Publication 6277

Published by..........................Technical Information Department
Collation..Cover, 9 leaves
First printing.................................175 unnumbered copies

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NWC TP 6277	2. GOVT ACCESSION NO. AD-A116810	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DEFINITIVE QUANTITY-DISTANCE TABLES FOR STORES OF EXPLOSIVES		5. TYPE OF REPORT & PERIOD COVERED Research report FY 1980-1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G. F. Kinney R. G. S. Sewell K. J. Graham		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Weapons Center China Lake, CA 93555		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS TA ZR000-01-01
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Weapons Center China Lake, CA 93555		12. REPORT DATE September 1981
		13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Quantity-distance tables
Explosives safety
Explosives storage

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See back of form.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(U) *Definitive Quantity-Distance Tables for Stores of Explosives*, by Gilbert F. Kinney, Robert G. S. Sewell, and Kenneth J. Graham. China Lake, Calif., Naval Weapons Center, September 1981, 16 pp. (NWC TP 6277, publication UNCLASSIFIED.)

(U) Metric tables of recommended safety distances away from quantities of explosives have been prepared for replacing our current English unit tables. These new tables use selected percentage increment values for distances in meters, and apply to conventional situations such as inhabited building distances, intraline distances, and magazine separations. Their range is about that of our current tables, and they use about the same number of increment steps.

(U) These new tables are based on exponential relationships, the exponents in which have theoretical background, and constants of proportionality that are based on accumulated experience with explosions. The method of construction of these new metric tables is briefly described.

CONTENTS

INTRODUCTION

Our forthcoming metrication will call for converting into metric our current English unit quantity-distance safety standards for stores of explosives. This conversion, however, is not a simple point-to-point process; thus the new metric tables should use rounded values that may not coincide with the English ones presently used. In this situation it becomes appropriate to review both historical and theoretical backgrounds for these important tables.

BACKGROUND

Prior to 1909 there was no accepted code defining safety distances for stores of explosives and no regulations concerning such stores. In these circumstances large stores of explosives could be, and in some cases actually were, stored in close proximity to centers of population or to important industrial areas. Disastrous results were then possible in case of an accidental explosion. Recognizing this unsafe situation, a technically knowledgeable group associated with the explosives industry prepared safety distance tables termed the "American Table of Distances" of 1910.[1] Two representative sets have been converted to metric units and are plotted to logarithmic coordinates in Figure 1 (Part A). These original specifications, since enlarged and revised, have served well as the basis for accepted safety practices for stores of both civilian and military explosives.

Safety distances in these and other tables are based on the premise that the energy release in an explosion is proportional to the quantity of explosives, and not greatly dependent on the particular type of explosive involved. This is a very reasonable assumption, particularly in view of the many uncertainties that may exist. The solid line of Part A of Figure 1 thus indicates the safety distances prescribed for inhabited buildings to be away from ordinary stores of explosives; the dashed line is for the safety distances prescribed to be away from barricaded stores.

[1] Ralph Assheton. *History of Explosions on Which the American Table of Distances Was Based.* New York, Institute of Makers of Explosives, 1930.

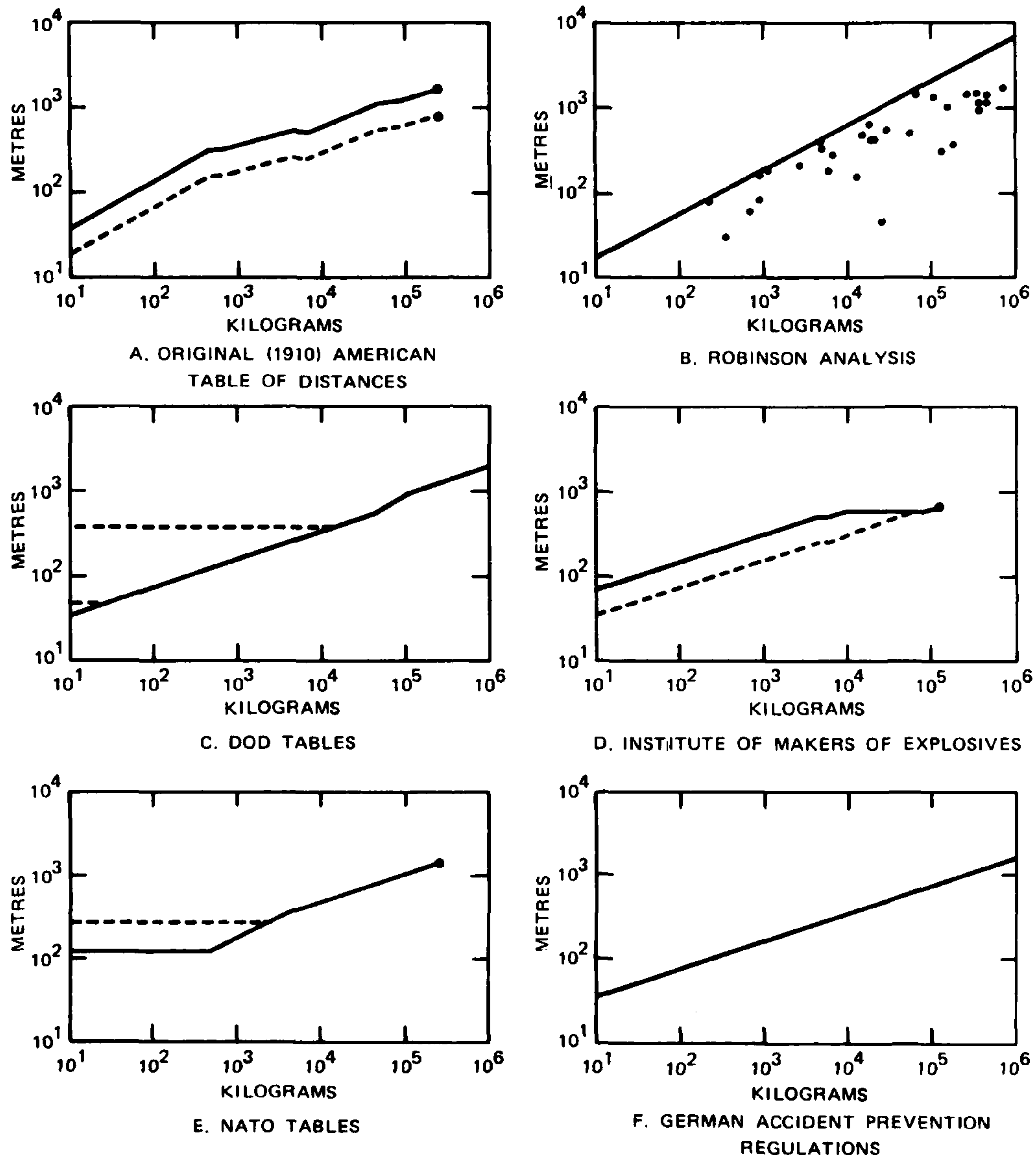


FIGURE 1. Various Quantity-Distance Relations for Inhabited Buildings (converted into metric units).

These latter, and smaller, distances were based on the misconception (since corrected)[2] that close-in barricades could contain large explosions.

These safety tables later were to a considerable degree confirmed by a statistical study of 34 accidental explosions of stores of military explosives,[3] the results of which are shown as Part B of Figure 1. The points there indicate the maximum distances observed for "more serious damage" to structures. The considerable scatter in the data can be attributed in large part to the fact that in any particular explosion there may have been no structure near the actual limit damage distance. Also shown in the figure is a suggested "limit line" providing distances adequate for prevention of "more serious damage."

CURRENT SPECIFICATIONS

Current Department of Defense Safety standards for explosive stores[4] are shown in Part C of Figure 1. The solid line there is for ordinary military explosives. The upper dashed line is for fragmenting munitions where larger distances are needed, and the lower dashed line is for small stores of explosive where protective blast mats are not provided. Comparison of Parts C and A of the figure indicates the updating[5] of the original tables needed in order to meet present requirements.

It is of interest to compare Department of Defense safety standards with the standards used by others. Those of the Institute of Makers of Explosives[6] are indicated in Part D of Figure 1. The upper line there is for inhabited buildings which are protected by close-by barricades; the lower line is for inhabited buildings not so protected. Part E of

---

[2] David W. Taylor Naval Ship Research and Development Center. *Origin and Subsequent Modification of Explosive Safety Quantity-Distance (ESQD) Standards for Mass Detonating Explosives With Special Reference to Naval Vessels*, by David Freund. Bethesda, Md., NSRDC, 1978. (DTNRSDC/SD-78-5, publication UNCLASSIFIED.) Available from Defense Technical Information Center, Washington, D.C., DTIC AD A058805.

[3] Army-Navy Explosives Safety Board. *The Present Status of the American Table of Distances*, by C. S. Robinson. Washington, D.C., A-NESB, 1945. (A-NESB Tech. Paper No. 1, publication UNCLASSIFIED.)

[4] Department of Defense. *DoD Ammunition and Explosives Safety Standards*, DoD Instr. 5154.45, 1976.

[5] Ballistics Research Laboratory. *The History of the Quantity-Distance Tables for Explosive Safety*, by Ona R. Lyman. Aberdeen, Md., BRL, 1979. (ARBRL-MR-0925, publication UNCLASSIFIED.)

[6] Institute of Makers of Explosives. *The American Table of Distances*. New York, IME, 1977. (Safety Library Pub. No. 2, publication UNCLASSIFIED.)

the figure shows the distances given in the NATO tables.[7] These indicate the relatively large distances prescribed for both fragmenting munitions (dashed line) and for ordinary explosives (solid line). Part F of the figure shows the quantity-distance relation designated by the German Accident Prevention Regulations.[8]

THEORETICAL

Comparison of the various parts of Figure 1 shows that the safety distances specified in the various tables at least approximately agree. Also, the various curves of that figure all show slopes of about one-third on logarithmic coordinates. They indicate, approximately, a cube root relation between quantity of explosive and the distance out to which it might cause damage. Now from theoretical considerations based on the physics of blast waves,[9] it has been shown that the distance out to which an explosion generates a given peak overpressure increases with the cube root of the explosive energy release. Hence the cube root relation tacitly assumes that peak overpressure is the determining factor for damage capability of an explosion. This assumption is widely accepted. However, it has recently been shown, from principles of analytical mechanics, that displacement and distortion effects of energy input into a mechanical member are a function of the impulse of the energy received within some minimum time.[10] Correspondingly, for a blast wave the overpressure-time integral (which also is the blast impulse per unit area) is actually responsible for target damage, provided that this blast impulse is received within target response time.[11] It was also shown that distances out to a specified blast impulse, for structures on the ground, increase with the 0.55 power of explosion energy release in explosions on the ground. It thus can be deduced that safety distances for inhabited buildings increase with the 0.55 power of possible explosion yield for conventional structures with ordinary response times.

---

[7] North Atlantic Treaty Organization. *NATO Safety Principles for the Storage of Ammunition and Explosives*. Brussels, NATO, 1969. (NATO AC/258-D/70.) Available from Defense Technical Information Center, Washington, D.C., DTIC AD 876078, publication UNCLASSIFIED.

[8] Rudolf Meyer. *Explosives*. Weinheim, Verlag Chemie, 1977.

[9] Gilbert Ford Kinney. *Explosive Shocks in Air*. New York, Macmillan, 1962.

[10] M. Kornhausen. *Structural Effects of Impact*. Baltimore, Spartan Books, Inc., 1962.

[11] Robert G. S. Sewell and G. F. Kinney. "Response of Structures to Blast; a New Criterion," *Ann. New York Acad. Sci.*, Vol. 152 (October 1968), pp. 532-547.

For very large explosions, however, blast wave durations may well exceed the response times for typical structures. In this case, only that portion of blast impinging on a target within its response time could cause damage. The pressure-time integral for damage then does not include the entire overpressure-time curve, but only its initial portion. The impulse effective in this case becomes approximately proportional to the initial peak overpressure in the blast. Then, and as indicated above, the distance out to a given damage capability increases with the cube root of the explosion energy release. Thus, for large explosions the distances specified for protection against damage should increase with the cube root of possible explosion yield.

These theoretical considerations indicate that the relation between the distance required for protection against damage by an accidental explosion and the quantity of explosives is directly proportional to the possible yield raised to some power, a power whose value is 0.55 for smaller stores of explosives and 1/3 for larger ones. It still remains, however, to establish values for the required constants of proportionality. For this, both judgment and compromise are required. Thus, values that are too large would specify unnecessarily great distances that are wasteful of both space and resources. Alternatively, values that are too small would specify inadequate distances for proper protection and give increased risk of damage.

To obtain optimum values for the constants of proportionality in these theoretically deduced quantity-distance relations, we rely on the accumulated experience on which the conventional quantity-distance tables are based, plus additional factual observations. Thus for lesser yields the exponent deduced here is 0.55, and this agrees rather well with the value 1/2 of the NATO expression for lesser yields. It also agrees quite well with the exponent 0.524 in an equation for the Robinson limit line shown in part B of the above figure, and also with the exponents 0.51 and 0.58 observed in recent field tests.[12] Furthermore, the distances of the NATO equation, the Robinson limit line, and the experimental results of Richardson and Bowman all agree quite well for lesser explosion yields. Therefore we can evaluate the required constant from a value representative of all these relations. This constant becomes, in metric units, 4.0 meters per kilogram TNT raised to the 0.55 power.

In the higher yield range, the exponent for the quantity-distance relation as deduced here is 1/3. This is in agreement with many portions

---

[12] David E. Richardson and Allen L. Bowman. "Sympathetic Reaction Tests and Analyses," in *Proceedings of the JANNAF Propulsion Systems Hazards Meeting, Monterey, Calif., October 1980*. Laurel, Md., Chemical Propulsion Information Agency, December 1980. (CPIA Pub. 330, pp. 355-376, publication UNCLASSIFIED.)

of the various quantity-distance relations described in the above. Moreover these relations all indicate about the same protection distance from specified (larger) stores of explosives. This required constant of proportionality thus is readily selected from representative quantity-distance values; this is found to be about 20 meters per cube root kilogram TNT.

Each of the two quantity-distance relations above pertains to a limited range of explosion yields with a transition between these where they show identical values. This is a yield of 1683 kilograms TNT (1.683 metric tonnes TNT) with a distance computed by either relation of 237.9 meters. The complete metric quantity-distance relation for stores of explosives is so established. In terms of radial distance R in meters and explosion yield in kilograms TNT, this is

$$R = 4.0\ W^{0.55} \qquad W < 1680\text{ kg}$$

$$R = 20\ W^{1/3} \qquad W > 1680\text{ kg}$$

Units: R, meters $\qquad$ W, kilograms

This deduced quantity-distance relation is shown graphically in Figure 2. The curve there pertains directly only to prescribed safety distances for inhabited buildings. It indicates a minimum safety distance of 380 meters away from fragmenting munitions, or 21 meters away from any explosive store, values based on current DoD and NATO tables.

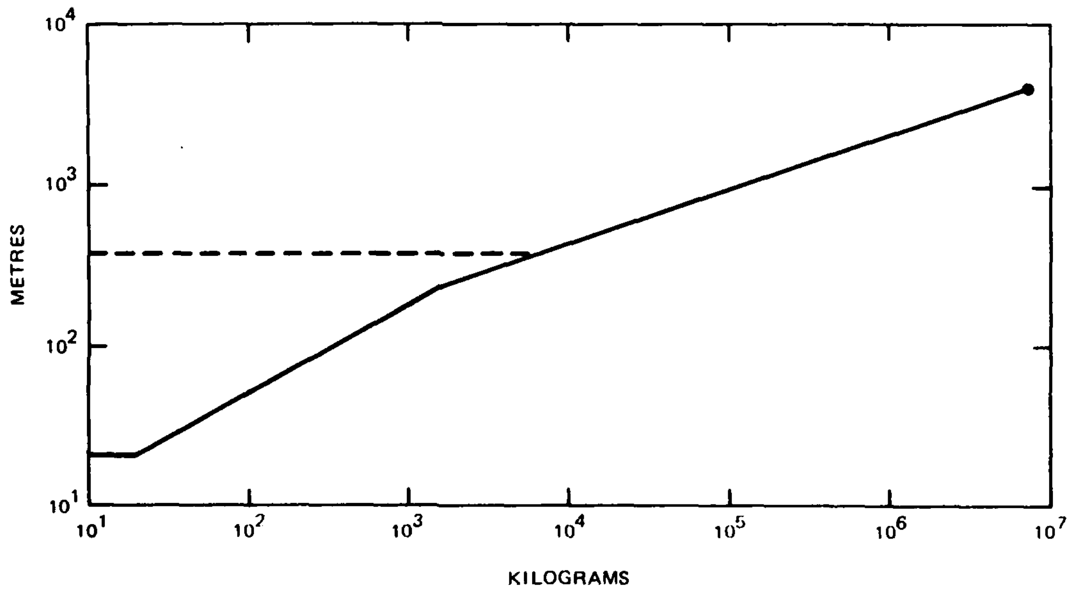


FIGURE 2. Recommended Safety Distances for Inhabited Buildings (in modern metric units).

Recommended protection distances for situations other than inhabited buildings are readily found from these basic data. Such situations in general involve either reduced risk or increased acceptable risk, and so require somewhat reduced safety distances.[13] Table 1 lists the multipliers of the DoD Ammunition and Explosives Safety Standard,[4] and these permit the inhabited building relations above to apply to other situations.

TABLE 1. Multipliers for Separation Distances.

Situation	Ratio to inhabited building distance
Inhabited buildings, aircraft parking areas, etc.	1.00
Public traffic routes	0.60
Between operating buildings (intraline distances)	0.36
With protective barricades	0.18
Magazine separations (selected situations)	
Standard earth-covered arch-type magazines, side by side	0.025
Above-ground magazines, not earth-covered	0.22

Safety distance tables (Tables 2 and 3) based on the above relations are included as part of this report. Table 2 pertains to inhabited buildings and to public traffic ways, and Table 3 pertains to intraline separations and to magazine spacings. The range of these metric tables is approximately the same as that of the English unit tables they are designed to replace. These metric tables use step-wise increments in kilograms of explosives, with approximately equal percentage increases between steps rather than equal amounts. For Table 2, this percentage increment is chosen so that there are 15 steps per decade, and the total number of steps is about that of the English unit tables; for Table 3, there are 13 steps per decade. The associated distance values are rounded ones that conform to the basic equation within about 1%.

---

[13] K. J. Graham and Gilbert F. Kinney. "A Practical Analysis System for Hazards Control," *J. Safety Research*, Vol. 12, No. 1 (Spring 1980), pp. 13-20.

TABLE 2. Safety Distances for Inhabited Buildings and for Public Traffic Ways.

Explosives, kg		Safety distance, m			
		Inhabited buildings		Public traffic ways	
Over	Not over	Frag. mun.	Chem. explo.	Frag. mun.	Chem. explo.
0	20	380	21	230	13
20	25	380	24	230	14
25	30	380	26	230	16
30	35	380	28	230	17
35	40	380	30	230	19
40	50	380	34	230	21
50	60	380	38	230	23
60	70	380	41	230	25
70	80	380	45	230	27
80	90	380	48	230	29
90	100	380	50	230	30
100	120	380	56	230	33
120	140	380	60	230	36
140	160	380	66	230	39
160	180	380	70	230	42
180	200	380	74	230	44
200	250	380	84	230	50
250	300	380	92	230	56
300	350	380	100	230	60
350	400	380	110	230	64
400	500	380	120	230	74
500	600	380	135	230	80
600	700	380	145	230	88
700	800	380	160	230	94
800	900	380	170	230	100
900	1000	380	180	230	105
1000	1200	380	200	230	120
1200	1400	380	215	230	130
1400	1600	380	230	230	140
1600	1800	380	245	230	145
1800	2000	380	250	230	150
2000	2500	380	270	230	165
2500	3000	380	290	230	175
3000	3500	380	300	230	180
3500	4000	380	320	230	190
4000	5000	380	340	230	205
5000	6000	380	360	230	220
6000	7000	380	380	230	230
7000	8000	400	400	240	240
8000	9000	420	420	250	250

TABLE 2. (Contd.)

Explosives, kg		Safety distance, m			
		Inhabited buildings		Public traffic ways	
Over	Not over	Frag. mun.	Chem. explo.	Frag. mun.	Chem. explo.
9,000	10,000	430	430	260	260
10,000	12,000	460	460	270	270
12,000	14,000	480	480	290	290
14,000	16,000	500	500	300	300
16,000	18,000	520	520	310	310
18,000	20,000	540	540	330	330
20,000	25,000	580	580	350	350
25,000	30,000	620	620	370	370
30,000	35,000	660	660	390	390
35,000	40,000	680	680	410	410
40,000	50,000	740	740	440	440
50,000	60,000	780	780	470	470
60,000	70,000	820	820	490	490
70,000	80,000	860	860	520	520
80,000	90,000	900	900	540	540
90,000	100,000	920	920	560	560
100,000	120,000	980	980	600	600
120,000	140,000	1050	1050	620	620
140,000	160,000	1100	1100	660	660
160,000	180,000	1150	1150	680	680
180,000	200,000	1150	1150	700	700
200,000	250,000	1250	1250	760	760
250,000	300,000	1350	1350	800	800
300,000	350,000	1400	1400	840	840
350,000	400,000	1450	1450	880	880
400,000	500,000	1600	1600	960	960
500,000	600,000	1700	1700	1000	1000
600,000	700,000	1800	1800	1050	1050
700,000	800,000	1850	1850	1100	1100
800,000	900,000	1950	1950	1150	1150
900,000	1,000,000	2000	2000	1200	1200
1,000,000	1,200,000	2150	2150	1300	1300
1,200,000	1,400,000	2250	2250	1350	1350
1,400,000	1,600,000	2350	2350	1400	1400
1,600,000	1,800,000	2450	2450	1450	1450
1,800,000	2,000,000	2500	2500	1500	1500
2,000,000	2,500,000	2700	2700	1650	1650
2,500,000	3,000,000	2900	2900	1750	1750
3,000,000	3,500,000	3000	3000	1800	1800
3,500,000	4,000,000	3200	3200	1900	1900
4,000,000	5,000,000	3400	3400	2050	2050
5,000,000	6,000,000	3600	3600	2200	2200
6,000,000	7,000,000	3800	3800	2300	2300

TABLE 3. Safety Distances for Intraline Separations and for Magazine Spacings.

Explosives, kg		Safety distance, m			
		Intraline		Magazine separation	
Over	Not over	Bar	Unbar	Earth covered	Not earth covered
0	50	6	13	1	6
50	60	7	14	1	6
60	70	7	15	1	6
70	80	8	16	1	6
80	100	9	18	1	6
100	125	10	21	1	7
125	150	12	23	2	8
150	175	13	25	2	8
175	200	14	27	2	9
200	250	15	30	2	10
250	300	17	33	2	11
300	350	18	36	3	12
350	400	20	39	3	13
400	500	22	44	3	15
500	600	25	49	3	16
600	700	26	52	4	18
700	800	28	56	4	19
800	1,000	32	64	5	22
1,000	1,250	36	72	5	24
1,250	1,500	40	80	6	27
1,500	1,750	43	86	6	29
1,750	2,000	45	90	6	30
2,000	2,500	49	98	7	33
2,500	3,000	52	105	7	35
3,000	3,500	54	110	8	36
3,500	4,000	58	115	8	38
4,000	5,000	62	125	9	41
5,000	6,000	66	130	9	44
6,000	7,000	68	140	10	46
7,000	8,000	72	145	10	48
8,000	10,000	78	155	11	52
10,000	12,500	84	165	12	56
12,500	15,000	88	180	13	60
15,000	17,500	94	185	13	62
17,500	20,000	98	195	14	66

TABLE 3. (Contd.)

Explosives, kg		Safety distance, m			
		Intraline		Magazine separation	
Over	Not over	Bar	Unbar	Earth covered	Not earth covered
20,000	25,000	105	210	15	70
25,000	30,000	110	225	16	74
30,000	35,000	120	235	17	78
35,000	40,000	125	245	17	82
40,000	50,000	135	270	19	88
50,000	60,000	140	280	20	94
60,000	70,000	150	300	21	98
70,000	80,000	155	310	22	105
80,000	100,000	165	330	23	110
100,000	125,000	180	360	25	120
125,000	150,000	190	380	27	130
150,000	175,000	200	400	28	135
175,000	200,000	210	420	29	140
200,000	250,000	225	450	31	150
250,000	300,000	240	480	33	160
300,000	350,000	250	500	35	170
350,000	400,000	270	540	37	175
400,000	500,000	290	580	40	190
500,000	600,000	300	600	42	200
600,000	700,000	320	640	44	215
700,000	800,000	330	660	46	225
800,000	1,000,000	360	720	50	240
1,000,000	1,250,000	390	780	54	260
1,250,000	1,500,000	410	820	58	270
1,500,000	1,750,000	430	860	60	290
1,750,000	2,000,000	450	900	62	300
2,000,000	2,500,000	490	980	68	330
2,500,000	3,000,000	...	...	72	350
3,000,000	3,500,000	...	...	76	360
3,500,000	4,000,000	...	...	80	380
4,000,000	5,000,000	...	...	86	410
5,000,000	6,000,000	...	...	90	440
6,000,000	7,000,000	...	...	96	460

The transition "point" at 1680 kilograms TNT (or 238 meters) computed above represents the situation where increased yields produce blasts with durations longer than response times of typical targets. This transition between lower and higher yields actually occurs over a range of values rather than at a mathematical point, but it is of interest to examine it. For this we use the scaling laws for explosions[9] and data for a reference explosion of 1 kilogram TNT in the unconfined atmosphere.[14]

From the scaling laws, the distance from a free air explosion at 1 kilogram TNT that corresponds to 238 meters from a 1680-kilogram-TNT explosion on the ground is found as $(238)/(2 \times 1680)^{1/3}$, where the factor 2 accounts for the hemispherical nature of explosions on the ground. At this scaled distance the peak overpressure in the blast wave is 60 millibars. This might well cause "failure of glass windows, large and small," but would not be expected to cause structural failure of a well-constructed building.[15] Similar characterizations can be expected to apply at the recommended protection distances for other quantities of stored explosives. Duration of the blast wave at the transition "point" can be computed from the scaled duration of 3.8 $ms/kg^{1/3}$ for the reference explosion at a scaled distance of 15.8 $m/kg^{1/3}$. The actual duration is found to be $3.8 \times (2 \times 1680)^{1/3} = 57$ milliseconds.

This computed duration time is to be compared with response times for typical structures. For well-knit structures it has been deduced[9] and verified by analogue computer studies[16] that response time to a typical blast wave is about 1/4 the natural period of vibration. It also has been ascertained in connection with earthquake vulnerability studies[17] that the frequency of natural vibration of ordinary one-story and two-story buildings is about 4 hertz. This corresponds to a period of vibration of 250 milliseconds, so that 1/4 of this, or about 62 milliseconds, becomes the estimated response time for ordinary structures. The agreement between this typical response time of 62 milliseconds as computed from engineering measurements on typical structures and the corresponding transition value of 57 milliseconds as computed from explosion theory, is perhaps fortuitous. Nevertheless, it supports the analysis methods of this report and lends confidence in its suggested quantity-distance relations.

---

[14] Naval Weapons Center. *Engineering Elements of Explosions*, by G. F. Kinney. China Lake, Calif., NWC, November 1968. (NWC TM 4654, publication UNCLASSIFIED.)

[15] U.S. Atomic Energy Commission. *The Effects of Nuclear Weapons*, ed. by Samuel Glasstone. Washington, D.C., AEC, 1962. Publication UNCLASSIFIED.

[16] Naval Weapons Center. *The Yawing Motion of a Finned Free-Flight Missile Produced by a Side-Thrust Rocket Motor*, by R. J. Stirton. China Lake, Calif., NOTS, 1953. (NAVORD Report 2070, publication UNCLASSIFIED.)

[17] University of California. *Earthquake and Blast Effects of Structures*. Berkeley, Calif., U. Calif., Engineering Research Inst., 1952.

CONCLUSIONS

It is deduced here from theoretical considerations that protection distances in a quantity-distance relation should increase with the 0.55 power of possible explosion yield for smaller stores of explosives, and with the 1/3 power for larger stores. The required constants of proportionality are then evaluated from accumulated experience and from actual damage data, providing the relations

$$R = 4.0\ W^{0.55} \qquad \text{for} \qquad W < 1680\ \text{kg}$$

$$R = 20\ W^{1/3} \qquad \text{for} \qquad W > 1680\ \text{kg}$$

for protection distances R in meters and explosion yields of W kilograms TNT. This relation applies directly to distances for inhabited buildings, but can be applied to other situations by introducing the multiplying factors of Table 1. It is strongly recommended that these relations be made the basis for our forthcoming metric tables. Representative metric tables are included.

INITIAL DISTRIBUTION

1 Assistant Deputy Chief of Naval Material for Laboratory Management
9 Naval Air Systems Command
  AIR-00D4 (2)
  AIR-3021 (2)
  AIR-350 (1)
  AIR-350D (1)
  AIR-512 (1)
  AIR-533 (1)
  AIR-541 (1)
5 Chief of Naval Operations
  OP-03 (2)
  OP-05 (1)
  OP-098 (1)
  OP-55 (1)
1 Chief of Naval Material (MAT-03)
3 Naval Sea Systems Command
  SEA-03 (1)
  SEA-99612 (2)
3 Chief of Naval Research, Arlington
  ONR-102 (1)
  ONR-461 (1)
  ONR-473 (1)
1 Air Test and Evaluation Squadron 5
1 David Taylor Naval Ship Research and Development Center, Bethesda
1 Fleet Anti-Air Warfare Training Center, San Diego
1 Marine Air Base Squadron 32, Beaufort
1 Marine Corps Air Station, Beaufort
1 Naval Air Engineering Center, Lakehurst
1 Naval Air Force, Atlantic Fleet
2 Naval Air Force, Pacific Fleet
1 Naval Air Station, North Island
2 Naval Air Test Center (CT-176), Patuxent River (Aeronautical Publications Library)
1 Naval Avionics Center, Indianapolis (Technical Library)
1 Naval Explosive Ordnance Disposal Facility, Indian Head
1 Naval Ocean Systems Center, San Diego (Code 1311)
1 Naval Ordnance Station, Indian Head (Technical Library)
7 Naval Postgraduate School, Monterey
  Code 012, Dean of Research (1)
  Code 06, Dean of Science and Engineering (1)
  Code 1424, Library (2)
  Code 61, Physics and Chemistry Department, Chairman (1)
  Code 61Ky, Dr. G. F. Kinney (1)
  Code 61Ri, Dr. R. A. Reinhardt (1)

5 Naval Surface Weapons Center Detachment, White Oak Laboratory, Silver Spring
WR-13, R. Liddiard (1)
J. Erkman (1)
Dr. S. Jacobs (1)
Guided Missile Warhead Section (1)
Technical Library (1)
1 Office of Naval Research Branch Office, Chicago
1 Office of Naval Research Branch Office, Pasadena
1 Operational Test and Evaluation Force, Norfolk
1 Pacific Missile Test Center, Point Mugu (Technical Library)
1 Army Armament Materiel Readiness Command, Rock Island (DRSAR-LEP-L, Technical Library)
4 Army Armament Research & Development Command, Dover
DRDAR-LCU-SS, J. Pentel (1)
Technical Library (3)
1 Aberdeen Proving Ground (Development and Proof Services)
6 Army Ballistic Research Laboratories, Aberdeen Proving Ground
DRDAR-BLT
P. Howe (1)
C. Kingery (1)
O. Lyman (1)
DRDAR-BLV
Vitali (1)
DRDAR-SEI-B (1)
DRDAR-T
Detonation Branch (1)
1 Army Material Systems Analysis Agency, Aberdeen Proving Ground (J. Sperrazza)
1 Army Research Office, Durham
1 Harry Diamond Laboratories, Adelphi (Technical Library)
1 Radford Army Ammunition Plant
1 Redstone Arsenal (Rocket Development Laboratory, Test and Evaluation Branch)
1 Rock Island Arsenal
1 White Sands Missile Range (STEWS-AD-L)
1 Yuma Proving Grounds (STEYT-GTE, M&W Branch)
1 Tactical Air Command, Langley Air Force Base (TPL-RQD-M)
3 Air Force Armament Division, Eglin Air Force Base
1 Air University Library, Maxwell Air Force Base
1 554th Combat Support Group, Nellis Air Force Base (OT)
2 57th Fighter Weapons Wing, Nellis Air Force Base
FWW/DTE (1)
FWW/DTO (1)
2 Tactical Fighter Weapons Center, Nellis Air Force Base
CC/CV (1)
COA (1)
1 Defense Nuclear Agency (Shock Physics Directorate)


ILMED